7.6 Roadside Channel (Type A) Design Procedure

7.6.1 General Design Considerations

The design of Type A channels shall consider flow capacity, economics, traffic safety, aesthetics, erosion control and maintenance. These considerations are usually interrelated to such an extent that optimum conditions cannot be met for one without compromising one or more of the others; the ideal being to achieve a reasonable balance.

The location, linings and cross slope of banks are important factors in safety considerations. Motorists' safety generally improves with increasing distance between the travelway and the channel. This distance may increase the cost of property acquisition which may be offset in part by a reduction in the cost of traffic protection. The channel may be located closer to the roadway if an errant vehicle can negotiate the lining and cross slope and recover.

All channels are to be designed so as to minimize erosion. Erosive velocities can be reduced by flattening channel grades where uniform flow conditions exist, otherwise an appropriate channel lining is to be used. To prevent erosion, all channels, ditches or swales will be lined as soon as they are excavated.

A roadside channel is defined as an open channel usually paralleling the highway embankment and within the limits of the highway right-of-way. It is normally trapezoidal or V-shaped in cross section and lined with grass or a special protective lining.

The primary function of roadside channels is to collect surface runoff from the highway and areas which drain to the right-of-way and convey the accumulated runoff to acceptable outlet points.

A secondary function of a roadside channel is to drain subsurface water from the base of the roadway to prevent saturation and loss of support for the pavement or to provide a positive outlet for subsurface drainage systems such as pipe underdrains.

The alignment, cross section and grade of roadside channels is usually constrained to a large extent by the geometric and safety standards applicable to the project. These channels should accommodate the design runoff in a manner which assures the safety of motorists and minimizes future maintenance, damage to adjacent properties, and adverse environmental or aesthetic effects.

7.6.2 Vertical Alignment

Grade affects both the size of the channel and the flow velocity. The flows should be kept subcritical wherever possible so as to avoid adverse characteristics of supercritical flow.

The approximate grade of a channel is usually determined by the topography of the site. If the terrain is flat then deposition of sediment is unavoidable, the channel should be designed so that the deposition will occur at a location accessible to maintenance.

"Vertical grade drops" or check dams, constructed of concrete walls, stones, gabions, concrete cribbing, metal cribbing or treated timbers, are very useful in maintaining grades which produce acceptable velocities downstream and reduce the costs of lining a channel. These should only be used in channels not accessible to vehicles.

7.6.3 Horizontal Alignment

A straight alignment of a channel permits a simplified hydraulic design. A straight channel does not provide obstacles to the flow and normally will not pick up materials for later deposition at some point downgrade. It is not usually practical to design a straight channel and have it compatible with the terrain or existing streams. Changes in alignment should be as gradual as the right-of-way and terrain permit. Whenever practicable alignment changes should be made in sections with a flat gradient, particularly if flows will become supercritical on a steeper slope. This practice will reduce the force of the water against the banks and allow the use of more effective erosion controls. When horizontal curvature is utilized, the effects of increased water surface on the outsides of curves should be considered.

7.6.4 Swales

Swales are shallow depressed areas used to drain medians, shelves with negative backslopes, and other areas where ditches are not feasible for either safety or aesthetic considerations. Grass-lined swales for the roadways generally have a longitudinal slope which conforms to the roadway grade except on flat grades, where the swale grade may be steeper than the roadway grade.

7.6.5 Interceptor Channels

These channels are used to intercept runoff from adjacent areas, to collect runoff from within the project, and to convey the runoff to suitable outlets, preferably watercourses. Interceptor channels or ditches are divided into three categories: Top-of-slope Channels, Toe-of-Slope Channels and Outlet Channels.

The layout of Interceptor Channels should be made on a topographical map which contains the project, location of storm drainage structures, contours, and drainage area limits.

For the purposes of payment and in accordance with the Department's Standard Specifications, a channel shall be interpreted to mean a natural or artificial watercourse having an average width at the bottom, after excavation, of 1.2m (4 ft) or more. A drainage ditch shall be interpreted to mean an unpaved, artifically constructed open depression having an average width of less than 1.2 m (4 ft) at the bottom, after excavation, constructed for the purpose of carrying surface water.

- **Top-of-Slope channels** or ditches are located at the top of cut slopes for the purpose of intercepting runoff from natural slopes inclined towards the project. They serve to reduce erosion of the cut slope face and to prevent debris and sediment from washing onto the project.

The following should be considered before use of a Top-of-Slope Channel:

- The runoff from the contributing area can flow down the cut slope if it will not affect its stability. The Soils and Foundations Section should be consulted to determine this. If the slope will not be stable, then a top-of-slope channel is required.
- If the cost of additional drainage resulting from the absence of a channel exceeds the cost of the channel, then the channel may be warranted. The fact that top-of-slope channels are far removed from the travelway and are difficult to maintain should also be considered.
- These channels are to have a trapezoidal section with 3 horizontal to 1 vertical side slopes for grass linings; and 2 horizontal to 1 vertical side slopes for riprap or rigid linings.
- The channel grade should be such that ponding will not occur thereby causing saturation or overflow at the top of the slope which could result in slope failure. In areas of unstable slopes it may be necessary to intercept, and accelerate the removal of runoff with pipes. Channels crossing highly permeable slopes may require lining with impermeable material.
- To prevent slope failure, the top of the channel nearest the slope should be located no closer than five feet from the outer limit of the rounding created at the top of cut slopes.
- Excessively deep channel cuts to maintain constant grades should be avoided.

• **Toe-of-slope channels** are located near the toe of the embankment when it is necessary to convey water collected by storm drainage systems, swales, or runoff from terrain inclined toward the projects, or to keep flow within the ROW until a suitable outlet is available.

These channels are to have the same cross section geometry as top-of-slope channels if their location will not be hazardous to vehicular traffic. If it is determined that a trapezoidal channel will be hazardous, then the use of guide railing must be considered. The preferred design, for both safety and aesthetics, would be a wide parabolic section with vertical curves to round all angles. The reduction of flow velocities through use of side, shallow channels or swales will minimize erosion and may be possible without an appreciable increase in cost. This type of channel may be found to be more economical after considering the cost of the guide rail, lining and rights of way required for alternatives.

If trapezoidal channels are used they should be located 1.5m (5 feet) from the normal toe rounding of the embankment to prevent the channel from being obstructed by any natural sloughing and erosion of the adjacent embankment. The 5 foot shelf shall be on a slope of 1V:12H between the toe and the top of the channel unless rights of way requirements dictate otherwise.

• **Outlet channels**

Outlet channels are used to convey flow from storm drainage systems and swales to a watercourse or to an area not subject to erosion.

They are usually designed with side slopes of 1V:2H. For vehicular safety, it may be necessary to use flatter side slopes and wider trapezoidal channels, especially where outletting swales from roadway cut sections to the toes of adjoining embankments.

Outlet channels should be located beyond the area required for vehicular recovery. They should be accessible for maintenance since they may trap sediment and debris.

7.6.6 Type A Channel Design Concepts

HEC-15 provides a detailed presentation of stable channel design concepts related to the design of roadside and median channels which convey a design discharge less than **1.42 m^3/s or 50 cfs**. This section provides a brief summary of significant concepts.

Stable channel design concepts provide a means of evaluating and defining channel configurations that will perform within acceptable limits of stability. For most highway drainage channels, bank instability and lateral migration can not be tolerated. Stability is achieved when the material forming the channel boundary effectively resists the erosive forces of the flow. Principles of rigid boundary hydraulics can be applied to evaluate this type of system.

Both velocity and tractive force methods have been applied to the determination of channel stability. Permissible velocity procedures are empirical in nature, and have been used to design numerous channels in the United States and throughout the world. However, tractive force methods consider actual physical processes occurring at the channel boundary and represent a more realistic model of the detachment and erosion processes.

The hydrodynamic force created by water flowing in a channel causes a shear stress on the channel bottom. The bed material, in turn, resists this shear stress by developing a tractive force. Tractive force theory states that the flow-induced shear stress should not produce a force greater than the tractive resisting force of the bed material. This tractive resisting force of the bed material creates the permissible or critical shear stress of the bed material. In a uniform flow, the shear stress is equal to the effective component of the gravitational force acting on the body of water parallel to the channel bottom. The average shear stress is equal to:

$$\tau = \gamma R S \qquad \textbf{(7.11)}$$

where: τ = average shear stress, Pa (lb/ft^2)
γ = unit weight of water, 9810 N/m^3 (62.4 lb/ft^3) (at 15.6 °C (60 °F))
R = hydraulic radius, m (ft)
S = average bed slope or energy slope, m/m (ft/ft)

The maximum shear stress for a straight channel occurs on the channel bed and is less than or equal to the shear stress at maximum depth. The maximum shear stress is computed as follows:

$$\tau_d = \gamma d S \qquad \textbf{(7.12)}$$

where: τ_d = maximum shear stress, Pa (lb/ft^2)
d = maximum depth of flow, m (ft)

Shear stress in channels is not uniformly distributed along the wetted perimeter of a channel. A typical distribution of shear stress in a trapezoidal channel tends toward zero at the corners with a maximum on the bed of the channel at its centerline, and the maximum for the side slopes occurs around the lower third of the slope as illustrated in Figure 7-7.

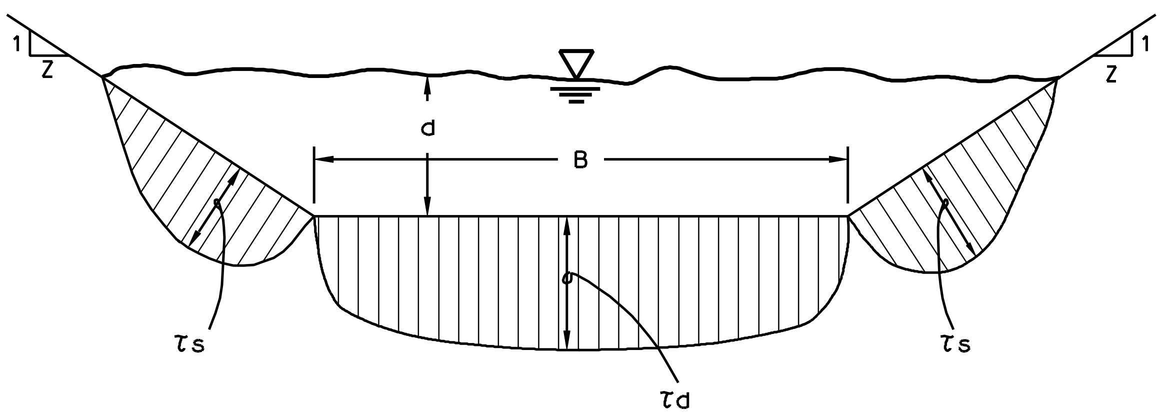

Figure 7-7 Distribution of shear stress

For trapezoidal channels lined with gravel or riprap having side slopes steeper than 3 horizontal to 1 vertical, side slope stability must also be considered. This analysis is performed by comparing the tractive force ratio between side slopes and channel bottom with the ratio of shear stresses exerted on the channel sides and bottom. The ratio of shear stresses on the sides and bottom of a trapezoidal channel, K_1, is given in Figure 7-9 and the tractive force ratio, K_2, is given in Figure 7-10. The angle of repose, θ, for different rock shapes and sizes is provided in Figure 7-11. The required rock size for the side slopes is found using the following equation:

$$(D_{50})_{sides} = \frac{K_1}{K_2}(D_{50})_{bottom} \quad \textbf{(7.13)}$$

where: D_{50} = the mean riprap size, m (ft)
K_1 = ratio of shear stresses on the sides and bottom of a trapezoidal channel (see Figure 7-9).
K_2 = ratio of tractive force on the sides and bottom of a trapezoidal channel (see Figure 7-10).

Flow around a bend in an open channel induces centrifugal forces because of the change in flow direction. This results in a superelevation of the water surface at the outside of bends and can cause the flow to splash over the side of the channel if adequate freeboard is not provided. This superelevation can be estimated by the following equation.

$$\Delta d = \frac{V^2 T}{g R_c} \quad \textbf{(7.14)}$$

where: Δd = difference in water surface elevation between the inner and outer banks of the channel in the bend, m (ft)
V = average velocity, m/s (ft/s)
T = surface width of the channel, m (ft)
g = gravitational acceleration, 9.8 m/s^2 (32.2 ft/s^2)
R_c = radius to the centerline of the channel, m (ft)

Equation 7.14 is valid for subcritical flow conditions. The elevation of the water surface at the outer channel bank will be $\Delta d/2$ higher than the centerline water surface elevation (the average water surface elevation immediately before the bend) and the elevation of the water surface at the inner channel bank will be $\Delta d/2$ lower than the centerline water surface elevation.

Flow around bends also creates secondary currents which impose higher shear stresses on the channel sides and bottom compared to straight reaches. Areas of high shear stress in bends are illustrated in Figure 7-8. The maximum shear stress in a bend is a function of the ratio of channel curvature to bottom width. This ratio increases as the bend becomes sharper and the maximum shear stress in the bend increases. The bend shear stress can be computed using the following relationship:

$$\tau_b = K_b \tau_d \quad \textbf{(7.15)}$$

where: τ_b = bend shear stress, Pa (lb/ft^2)
K_b = function of R_c/B (see Figure 7-12)
R_c = radius to the centerline of the channel, m (ft)
B = bottom width of channel, m (ft)
τ_d = maximum channel shear stress, Pa (lb/ft^2)

The increased shear stress produced by the bend persists downstream of the bend a distance L_p, as shown in Figure 7-8. This distance can be computed using the following relationship:

$$L_p = \frac{0.736\,R^{7/6}}{n_b} \qquad \left(L_p = \frac{0.603R^{7/6}}{n_b} \right) \qquad \textbf{(7.16)}$$

where: L_p = length of protection (length of increased shear stress due to the bend) downstream of the point of tangency, m (ft)
n_b = Manning's roughness in the channel bend
R = hydraulic radius, m (ft)

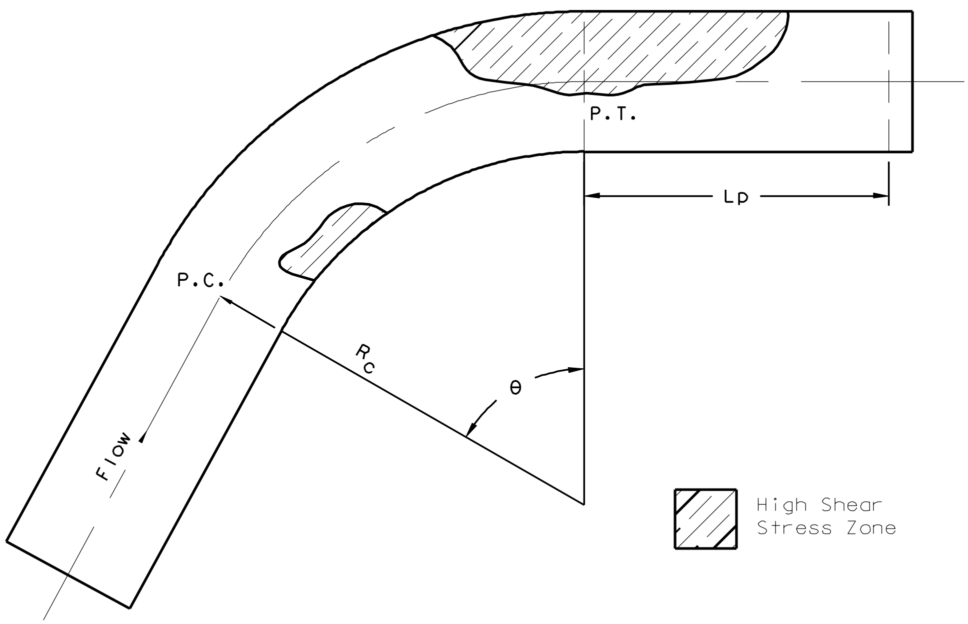

Figure 7-8 Shear stress distribution in channel bends